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High Definition 3D Printing – Comparing SLA and FDM Printing Technologies

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ABSTRACT

For consumer level additive manufacturing, there are currently two main methods to 3D print objects: Stereo lithography and Fused Deposition Modeling. Both processes add material, layer by layer, to create objects. Stereo lithography (SLA) uses a UV light source to selectively cure resin while Fused Deposition Modeling (FDM) extrudes semi-liquid plastic in a specific layout to create objects. As with most technologies, both styles of printing have advantages and disadvantages. The biggest advantage of SLA 3D printing is very high resolution. SLA 3D printing can produce objects with more than double the resolution of FDM printers. The mUVe 3D SLA printer and a Makerbot Replicator 2x were used in this paper. The mUVe 3d SLA printer is different from most SLA 3D printers that use a galvanometer or Digital Laser Projector (DLP) as a light source, the mUVe 3D printer uses a UV laser mounted on a Cartesian coordinate gantry system to cure the resin. This research focuses on the difference between the Cartesian coordinate gantry system and the standard galvanometer or DLP approach. Portions of the mUVe 3D printer were redesigned and the function of the 3D printer was tested by comparing print quality after the redesign was implemented. After the design revisions were implemented, the machine produced smoother parts and consistent functionality was improved. The resolution, determined by microscope measurement analysis, of the mUVe 3D printer was found to be significantly better than an FDM printer, however, SLA printers are more difficult for consumers to calibrate and use at home. This better resolution was the result of the much smaller deposition (laser) diameter on the mUVe compared to an FDM printer (nozzle).

INTRODUCTION

3D printing has been changing the manufacturing and prototyping industries since the late 1980's [1], but it wasn't until 2009 that "desktop" 3D printers were readily available to the public [1]. A desktop 3D printer is industry jargon for a smaller, less expensive 3D printer that a typical consumer can buy. It is simple enough to operate that an average consumer can navigate the 3D printer controls without extensive training. Typically, these printers are the Fused Deposition Modeling (FDM) type which use an extruder that melts a plastic filament to build parts. In 2011, Stereo lithography (SLA) desktop 3D printers became available with the B9Creator [2] and the Form 1 [3]. SLA 3D printers use a UV (ultraviolet) curable resin and a UV light source to make solid objects. Typically, one of three different UV light sources is used: a DLP (digital light processing) projector, a laser tuned to a specific wavelength, or LEDs.

As with most differing technologies with the same end goal, there are tradeoffs between SLA and FDM. One of the main advantages of SLA 3D printing is that it has a very high resolution with very thin layers. This allows intricate details to be printed in the objects. However, the liquid resins used for SLA 3D printing can be difficult to work with – especially at the consumer level. The SLA printing process is also slower than the FDM process. The FDM process cannot print with the same resolution as an SLA printer, but the spools of plastic filament for the FDM printer are much easier to use and they are more readily available.

Since 2009, when some of the most restrictive 3D printing patents expired, the 3D printing community (also known as "makers") generated a significant amount of knowledge on the FDM process and shared this knowledge with the world via open source websites and forums. However, very little information is available on SLA printing via lasers mounted on a Cartesian coordinate gantry system, the mUVe 3D printer was chosen for this project. Purchased as a kit, this printer was built (according to specifications) and tested, re-designed with improvements to the original design, re-built, and tested. The mechanics and process of printing with this printer were compared to an FDM printer. In addition, the resolution of parts produced by each printer was compared via the layer height and "nozzle" diameter specifications.

The higher resolution of SLA style 3D printing allows makers to do more with 3D printing. One common application of SLA printing is prototyping medical instruments that require small accurate parts. FDM type 3D printers do not have high enough resolution to print these types of objects at the proper scale. Many other applications exist that would benefit from small, accurate prototypes; however, until an inexpensive and reliable SLA printer is developed, this technology will likely be used only by well-funded projects.

Technology Comparison – SLA vs FDM

Machine Setup

SLA printers require several steps to initiate a print operation and obtain a finished product. First, the reservoir is attached to the frame of the machine. Screws and an L-bracket, shown in Figure 1, are used to clamp the reservoir so that is doesn’t lift/shift during printing. Next, the build plate is inserted into its mounting device. After these parts are assembled, the resin is prepared and poured into the reservoir. Proper and careful completion of each step is required for a successful print job. All of these steps require a skilled and trained operator. After each step has been completed, the print job is ready to be initiated.

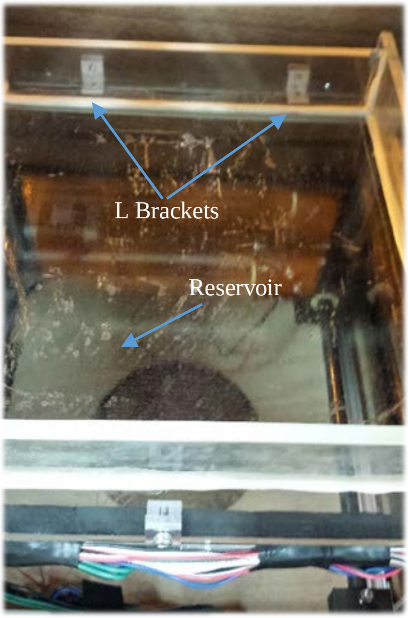


Figure 1: L Brackets and Reservoir

The operator time required to setup a traditional FDM printer is significantly less than an SLA printer and the setup procedures is much simpler, although the overall setup time is similar. The setup for an FDM print operation includes installing a spool of filament and pre-heating the machine to the proper temperatures. Neither process requires significant training or precision.

Although the setup times are roughly equivalent for the two types of printers, the setup difficulty level is much different. For SLA printing, the liquid resin can be very messy as it is difficult to keep the resin from spilling throughout the setup. Therefore, clean up after a job has finished is also time consuming. Cleaning up an SLA print job requires the removal of the entire build plate and removal of the part from the build plate. In addition, the reservoir has to be removed and leftover resin is placed back into storage. If the resin is left in the reservoir too long after the job is completed, it will cure in the reservoir, damaging the reservoir and wasting material. After the part is removed from the build plate, it is rinsed with isopropyl alcohol to remove excess resin and give the part a nice smooth finish. At this point, the part isn't fully cured, it must still be placed in a UV chamber or in direct sunlight to finish the curing process. The cleanup process for an FDM print job only consists of removing the part from the build plate. The FDM printer is then ready for another project.

Printing Time

The ability to create objects/prototypes quickly was one of the main reasons 3D printing was created. The time and money required for a 3D printer to create a prototype is significantly less than the time and money needed to manufacture the same prototype using traditional manufacturing processes. Although printing parts on the mUVe SLA printer is still much faster than traditional manufacturing, it is much slower than an FDM printer. Printing the same part will generally take the mUVe printer anywhere from 2 to 4 times longer than a desktop FDM printer. This is due to the laser diameter being much smaller than the nozzle diameter of FDM printers and the vertical layers being much smaller on the mUVe printer. Although the SLA printer takes longer to print, it can make objects that have a greater resolution than an FDM printer. The "SDSU Campanile" referenced in Table 1 is shown in Figure 2 (Campanile is 25mm tall). This object was printed using the mUVe 3D printer. Printing would not be feasible (at this scale) on an FDM printer because of the level of resolution required. Table 1 shows a comparison of printing times for the mUVe printer and a standard desktop FDM printer. (Note – Print times provided are theoretical time calculations generated by the printing software used to operate the printer, Repetier-Host [5]. While these times are usually not exact, they do provide approximate printing times.)

Table 1: SLA and FDM[1] Printing Time Comparison

Part	mUVe Time (min)	FDM Time (min)
SDSU Coin	129m	27m
Campanile	167m	45m
Tensile Test Sample	260	115m

Figure 2: SDSU Campanile Printed on mUVe 3D

Resolution

There are several methods used across the industry to compare 3D printer resolution. The simplest and most common method uses the nozzle (or laser) diameter and the minimum vertical layer height. By this standard, the mUVe performs much better than the FDM printer. The mUVe 3D printer can support a laser diameter as small as 0.1mm and a vertical layer height of 0.1mm. The standard nozzle diameter for a desktop FDM printers is 0.4mm and a vertical layer height of 0.2mm.

mUVe 3D Printer Design

mUVe 3D Printer Mechanical Systems

The SLA printer used in this research study (the mUVe 3D printer) was equipped with a 50mW 405nm laser mounted to a Cartesian coordinate gantry system that allows the laser to slide along an X and Y axis to cure the resin. For this particular style of SLA printer, the build plate only moves up in the Z axis, allowing the objects to be built layer by layer.

The mUVe 3D printer kit was assembled as specified by the manufacturer. Figure 3 shows the fully assembled printer and the location where the resin is poured into the reservoir. In this figure, the build plate is shown above the reservoir. To initiate the print job, the build plate is lowered into the reservoir so that the first layer of the print is cured onto the build plate. The X and Y axis are controlled by four stepper motors, two on each axis – this is two more motors than required for most FDM style printers.

To build the first layer of the object, the build plate is lowered to a distance of one layer thickness away from the reservoir bottom and then raised by increments of one layer thickness after each layer is completed. After each layer is cured by the laser, the resin is attached to both the reservoir bottom and the build plate (or the previous layer of the part). If the build plate is raised equally and simultaneously on both sides of the build plate, there is a high probability that the printed object will either become separated from the build plate and stay attached to the reservoir, or the object will fragment into several pieces with some pieces sticking to the reservoir and some pieces sticking to the build plate. Thus, the build plate is “peeled” away from the reservoir one side at a time, with the hope that the printed layer only adheres to the previous layer instead of the reservoir. In a “peel move”, the left side of the build plate is slowly raised to peel the left side of the object from the reservoir, followed by the right side of the build plate raising to complete the peel. Both sides of the build plate are then slowly lowered to a distance of one layer thickness above the previous z-axis position.

Due to the peel move, the Z-axis of the machine needs to be able to tilt/flex to allow the build plate to be peeled away from the reservoir. As specified by the manufacturer, the Z-axis setup shown on the machine in Figure 3 was unstable and did not slide smoothly up and down. In addition, when the peel move was being executed the entire Z-axis frame bent to accomplish this move. As a result, a new Z-axis was designed and built as shown in Figure 4. This new design allows the cross member connecting the two threaded rods to rotate freely at the connection point. The frame of the Z-axis is rigid, but the peel move can still be executed because the build plate rotates. Each SLA printing company tackles this issue of peeling the parts in a slightly different manner. Some use the Z-axis tilt method, while others tilt the reservoir instead of the build plate, and some rotate the reservoir to shear the bond between the part and the reservoir. While the Z-axis for the mUVe 3D printer was being redesigned, the mUVe company was also developing a similar redesign of the Z-axis.

In addition to the peel movement, a non-stick coating is applied to the reservoir to help prevent the parts from sticking to the reservoir. The non-stick coating process is also a tedious and difficult process for SLA printing preparation. This task may be too difficult for the average consumer.

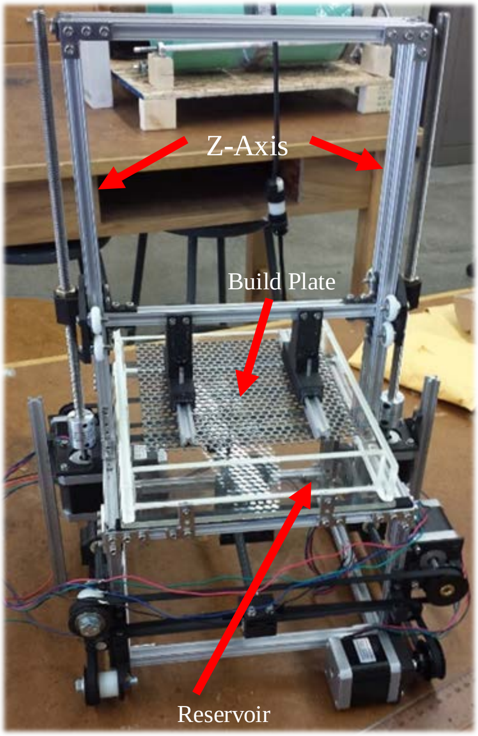


Figure 3: mUVe 3D SLA Printer Build Process

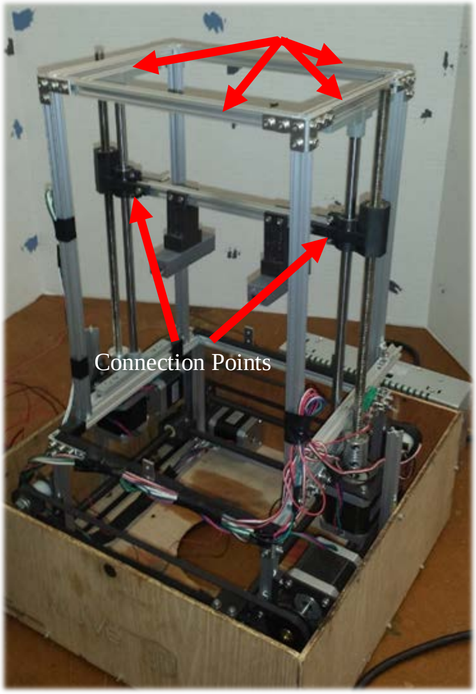


Figure 4: New Z-Axis Design

mUVe 3D Printer Electronics

An Arduino Mega control board with a RAMPS 1.4 shield were used to control the printer along with a modified open-source “Marlin” code, all of which is commonly used within the 3D printing community. A RAMPS 1.4 shield is a separate printed circuit board that attaches to an Arduino Mega microcontroller which controls stepper motors as well as extruders and fans [4]. The mUVe 3D printer is custom enough that several modifications to the Marlin code were required to account for these differences, including an increased number of motors to drive the X and Y axis, the removal of all temperature sensing and limitations based on temperatures, and the reconfiguration of end stop locations to ensure the machine knew the correct location of the laser and would not crash and damage itself.

Several options available within the RAMPS 1.4 Arduino shield to adjust the micro stepping of the motors. For most 3D printers, 1/16 micro stepping is used, however, the mUVe 3D printer uses 1/16 micro stepping only for the x- and y-axis, while a¼ micro stepping is used for the z-axis to provide the Z-motors more torque to peel the object from the reservoir.

The electronics to control and power the 50mW laser are a significant deviation from the standard FDM printer electronics. The laser is powered by an external laser driver and a transistor to control voltage. The RAMPS 1.4 shield is configured to use FDM extruders, so the addition of laser drivers is a significant change from normal wiring and operation. All of the electronics are designed to move the laser along the gantry system according to G code commands (similar to FDM 3D printers and traditional CNC machining).

In the mUVe system, the software package “Repetier-Host” [5] was used to control the mUVe printer along with sending G code commands to the printer. To generate the proper G code commands, the software package Slic3r [6] was used to generate a G-code, which “slices” the object to be printed into layers which are then printed layer by layer. This combination of Slic3r and Repetier-Host is very common in the additive manufacturing community and is considered standard among the open sourced desktop maker community.

Laser Calibration Process

After the printer was assembled, all electronics were connected properly and the correct software was loaded to the Arduino, the machine still required adjustment and calibration. Adjusting the laser is a two-step process, including focusing the laser and adjusting the diaphragm to filter out any diffraction. The laser and diaphragm assembly are shown in Figure 5.

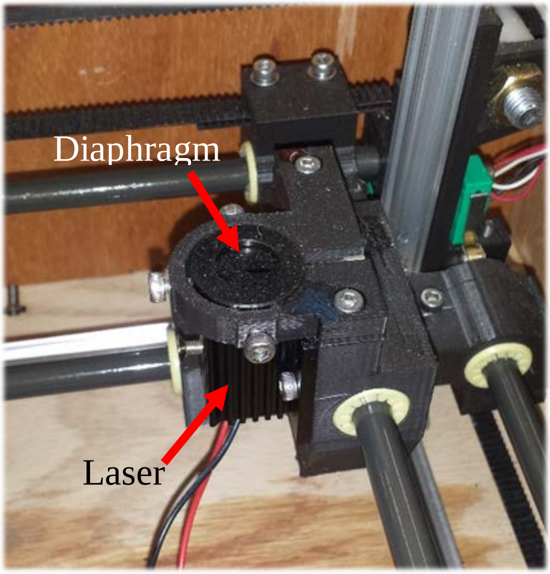


Figure 5: Laser and Diaphragm

The laser was focused by placing a sheet of paper in the reservoir and turning the focus adjustment screw on the laser until there was a point beam shown on the paper. Next, the diaphragm was installed and adjusted until the point on the paper was as small and bright as possible.

One of the most important and difficult calibration steps is determining the diameter of the laser beam. In a traditional FDM 3D printer, the nozzle is a fixed diameter hole drilled through a brass cone, and thus the diameter of each line is known exactly. In the case of the mUVe 3D printer, the “nozzle” diameter is the diameter of the laser. For this laser and diaphragm, the diameter should nominally be 0.1 mm, but can vary by adjusting the diaphragm opening. Because of the small size of the laser point and the manual hand adjustment required to adjust the diaphragm, it is very difficult to get the laser diameter to the exact nominal measurement. It is also very difficult to measure the exact size of the laser diameter using traditional measuring techniques (i.e. a caliper or ruler). With this in mind, the laser diameter was measured by creating a hollow square in which there was a known number of laser passes based on the assumed laser diameter. For example, if the laser diameter was assumed 0.1mm, the hollow square was made with a wall thickness of 1 mm which would mean 10 passes of the laser. Figure 6 shows a theoretical laser path for the hollow square with 1mm thick walls. This theoretical rendering is provided by the Repetier-Host software to allow the user to understand how the part will be manufactured before the process starts.

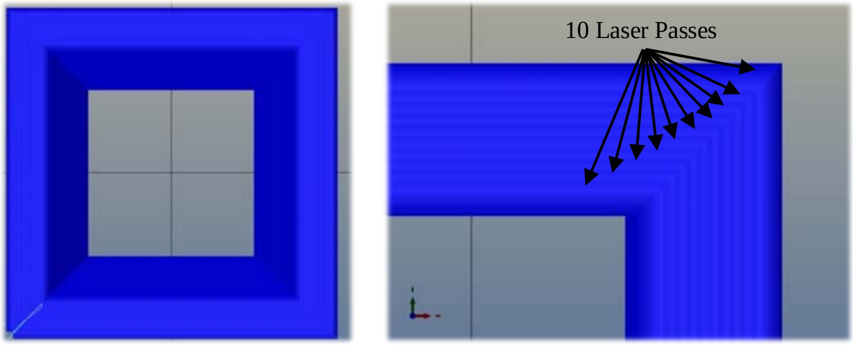


Figure 6: Calibration Cube Theoretical Rendering

This is still too small to accurately measure using traditional measurement techniques, so the calibration cube was analyzed under a microscope and the individual passes were counted and line thicknesses were measured. If the lines created by the laser had gaps in between them, the laser was smaller than assumed. If the lines overlapped, the laser was larger than assumed. Using this technique, and several iterations, the laser diameter was measured and proper adjustments were made in the software to account for the proper laser diameter. This is not a procedure that the average consumer could be reasonably expected to recreate without significant investment in microscopy equipment.

RESULTS

Laser Diameter

The laser diameter was measured using the process previously discussed. The laser diameter can be changed at any time by adjusting the diaphragm connected to the laser, so this process is necessary any time the laser diaphragm is adjusted, the printer is moved or significantly bumped. Before the calibration process, the laser diameter was assumed to be 0.1mm. A hollow cube was made with 1mm wall thickness (10 passes of the laser) as shown in Figure 7. The picture on the left shows the entire hollow cube at 20x magnified. At 20x, the object looks fine, but we know from previous attempts at printing complex objects that the laser diameter is not adjusted properly. At 150x, it is difficult to tell where one laser pass begins and one ends, suggesting overlapping laser paths. This indicates that the laser diameter is greater than 0.1mm.

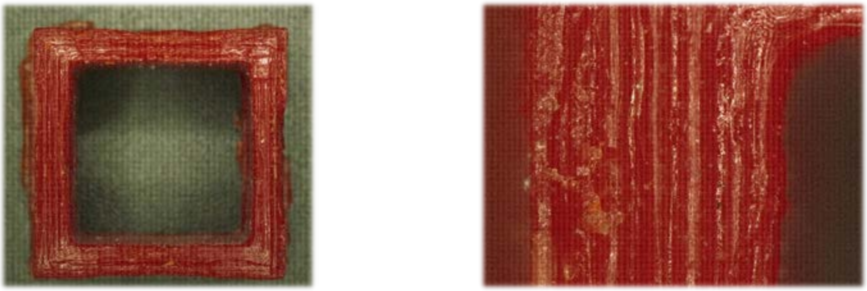
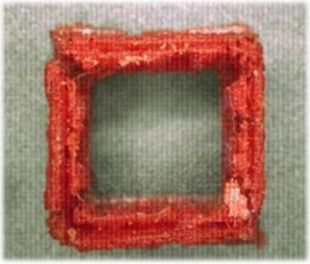


Figure 7: 0.1 mm Laser Diameter (20x – left, 150x – right)

Next, the laser diameter was adjusted in the Repetier-Host software to 0.2mm. The same hollow square was made – except with a wall thickness of 2mm (10 passes of the laser). Figure 8 shows the result of this print with the updated settings. As shown in the figure, the laser diameter was less than 0.2mm because there are clearly gaps in between passes. The microscope was then used to measure the thickness of a single pass. The passes were measured to be an average of 0.14mm.



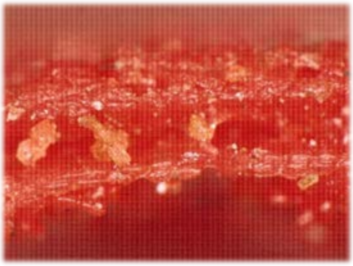


Figure 8: 0.2mm Laser Diameter (20x – left, 200x – right)

With the new laser diameter setting of 0.14mm, another hollow cube was made with a wall thickness of 1.4mm (10 passes). A laser diameter of 0.14mm is a somewhat odd diameter to use, however, it is easier to adjust the laser diameter size in the software to match the actual laser diameter rather than adjusting the diameter of the laser and starting the process over again. Figure 9 shows that with this setting, the hollow cube had very smooth layer lines and nice connection between toolpaths, further indicating that this is the correct laser diameter. The laser paths aren’t perfect because of the variations in the laser travel due to the gantry system moving the laser.

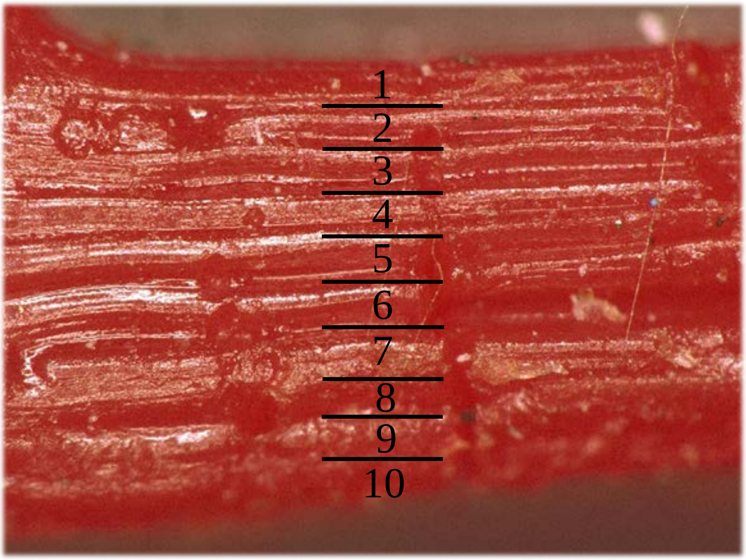


Figure 9: Correct Laser Diameter: 0.14mm (200x)

Z-Axis Design

The Z-axis design specified by the manufacture was not very stable and did not operate smoothly. As seen in Figure 3, the two Z-axis support members were mounted very close together, leaving the system very unstable and inconsistent. Furthermore, the rollers that were used to slide the Z-axis did not perfectly align with the channels they were designated to slide through, decreasing the consistency because sometimes the rollers would catch in their grooves causing the Z-axis to not be perfectly level. For these reasons, the Z-axis was redesigned. With the new design implemented, parts were repeatedly made with identical results showing the consistency of the new design. In fact, no parts were successfully printed using the original Z-axis design because the travel of the axis was not smooth enough to allow for a single layer to build properly.

DISCUSSION

Many ideas and projects require parts with complex geometry and small features that a standard FDM 3D printer is not capable of printing. An inexpensive, reliable, high definition SLA 3D printer will allow projects to be completed faster and cheaper through rapid and simple prototyping. Although successful prints were produced with this machine, there are opportunities to make this machine more reliable and produce higher quality.

Another option to cure the resin is to use a DLP projector as a UV light source instead of the laser on a gantry system that is currently used. This upgrade would increase the quality and reliability of this 3D printer and ease of use for the common user. The DLP projector would remove the gantry system that is responsible for many of the inconsistencies and problems with the current system. The laser diameter measurement process would also be avoided; another cause of significant set up time and frustration.

Another benefit of the DLP upgrade is the speed of a DLP system. Because a DLP projector produces an entire layer at a time, the print time is significantly reduced. In DLP projection systems, the speed is reduced to print times similar to FDM printers.

CONCLUSION

FDM and SLA 3D printers operate on the same principles of creating objects by adding layers of material, also known as additive manufacturing. As with many competing technologies, it is difficult to compare and determine which type is “better”. Both types of printers have strengths and weaknesses. An SLA printer can produce products with a much higher resolution than an FDM printer, but does so at the expense of speed. In addition, the process of using an SLA printer is more complicated than an FDM printer because the resin can be difficult to work with and overall the setup and clean up times are longer.

There are many applications to support both types of printers. In many general 3D printing applications, an FDM printer is appropriate. The setup and cleanup is simple and the printing process will be quick. However, when extra detail is needed, FDM printers will not be adequate and an SLA printer will be required. Therefore, both pieces of equipment are essential for modern day engineering fabrication and prototyping laboratories.

ACKNOWLEDGEMENTS

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